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Nesting characteristics of the olive ridley turtle (*Lepidochelys olivacea*) in Cabo Pulmo, southern Baja California

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Abstract Baja California represents the northernmost reproductive area for *Lepidochelys olivacea*. This region is characterized by its high temperature and low humidity. Thus, nest site selection plays an important role in reproductive success. To evaluate the factors affecting site selection for oviposition Las Barracas Beach, located in the south of the peninsula, was visited, from August to November 2000, in weekly periods. A density of 2.55 nests ha⁻¹ was estimated from a total of 55 nests counted. A hatching success of 73.7% was observed, with 23.7% mortality and 2.5% of eggs without apparent development (eggs counted=4,031). On the day of oviposition, the relative surface humidity (between 0.75% and 1.75%) and temperature (32°C) preferred by the females for nest construction was determined at the nest site, as well as the mean distance between the nests and the high tide line for that day (17.65 m). Hatching success was affected by humidity and distance. In addition, hatching success was higher between 10 and 30 m above the high tide line measured on the day of oviposition (surface humidity ca. 1%). A total of 874 hatchlings were measured, with an average of 42.1 mm straight carapace length. Larger sizes were found in October and smaller ones in November. Generally speaking, the sizes found here were larger than those obtained in other areas. This is probably due to two factors: (1) the nests in Las Barracas were kept in situ, whereas in other areas nests are sometimes incubated artificially and (2) the nesting population of

southern Baja California is different from the eastern Pacific population.

Introduction

Nest site selection has an important role in the reproduction of all sea turtle species, since conditions inside the nest directly affect incubation period (Wood and Bjorndal 2000), survival of hatchlings (Horrocks and Scott 1991), hatchling size (Packard and Packard 1994), hatchling growth (Foley 2000), and sex determination (Salame-Méndez 1998). General conditions are required such as smooth-sloped sandy beaches and certain humidity levels; however, sometimes other characteristics, such as grain size, salinity, and water tables, may force females to change their nesting behavior (Ehrenfeld 1979).

The olive ridley turtle (*Lepidochelys olivacea*) generally chooses beaches with high humidity levels. Most of these are found near river mouths or estuaries (Casas-Andreu 1978; Márquez 1996). Its primary nesting areas are Gahimarta, on the northeastern coast of India, with a record of 800,000 females per season (Anonymous 1994) and in the eastern Pacific, along the west coast of Mexico, from Sinaloa (especially Escobilla Beach in Oaxaca) to Costa Rica, with records of almost 200,000 females per season (Fritts et al. 1982; Márquez 1996).

Though not within this range, the Baja California peninsula is considered one of the most critical areas in Mexico for the conservation and research of sea turtles (Nichols and Seminoff 1994; Nichols et al. 2002). Its waters represent an important feeding ground for all sea turtle species along the Pacific coasts of Mexico and a marginal reproductive area for leatherback turtle (*Dermochelys coriacea*) and olive ridley turtle (*L. olivacea*) (Casas-Andreu 1978; Fritts et al. 1982). Nesting of *L. olivacea* at the southern end of the peninsula has not been studied in detail although this area represents the

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northernmost limit of reproduction for this species (Los Cabos region to La Paz Bay) (Fritts et al. 1982). Environmental conditions, however, are different here from nesting areas along the coast of mainland Mexico, since southern Baja California is a semiarid zone characterized by its low humidity and high temperature (INEGI 2000); characteristics that may make oviposition difficult.

In the present paper we quantified nest density and characterized the nesting of a *L. olivacea* colony at Las Barracas Beach, in the Los Cabos region of southern Baja California, in order to determine the most influential environmental factors in the selection of suitable sites for oviposition.

Materials and methods

Study area

Cabo Pulmo is located at the southern tip of the Baja California peninsula (23°26'N; 109°25'W; Fig. 1). Its coral reef harbors areas of some of the greatest marine biodiversity found along the Mexican coast. It is also one of the most attractive underwater areas in the Sea of Cortes (Anaya-Reyna 1993), which is the reason why it was decreed a National Marine Park (Anonymous 1995). Las Barracas is one of three bays that constitute the park and is located north of Cabo Pulmo. It has a sandy beach of about 4 km in length, with a grain size from coarse to medium (according to the methodology of Narro-Farías 1994). The beach is approximately 60 m wide from the high tide line to the beginning of dune formations and has a soft slope. In this area we observed nestings of *Lepidochelys olivacea* between July and November, as has previously been registered at the southern tip of the peninsula (Renán-Galindo 1995).

Weather in this region is dry and very hot, characterized by extreme temperatures during the day. The average annual temperature is 24°C, with an average of 30°C from July through September. Average yearly precipitation varies from 200 to 300 mm, and the rainy months are August, September, and October when the hurricane season starts (INEGI 2000).

In situ observations

From August to November 2000 we made nightly patrols at Las Barracas Beach 4 days week⁻¹ (from 7 p.m. to 7 a.m.), at 3-h intervals, to locate nesting females or nests recently made (Renán-Galindo 1995). In order to monitor the number of nests and time of development, we marked every nest with a stake on which the date and a serial number were recorded. Distance between the nest and the high tide line was obtained with a measuring tape (± 1 cm). We evaluated humidity of the site selected by the female, taking a sample of sand (100–200 g) at a depth of 5 cm, 1 m away from the nest, and

at the same distance from the high tide line. The sample was collected in a labeled hermetic bag to avoid loss of humidity during transportation to the laboratory. Once there, we determined relative humidity using the dry weight method (Hernández-Dávila et al. 1991). We used additional samples taken every 2.5 m over the track left by the female to determine a possible humidity gradient and then made comparisons between the selected site and those rejected by the female (Wood and Bjorndal 2000).

We recorded sand temperature using a soil thermometer ($\pm 1^\circ\text{C}$) at a depth of 5 cm, 1 m away from the nest, and at the same distance from the high tide line. We also measured the temperature every 2.5 m over the track left by the turtle. With the data obtained we were able to compare the selected site and those rejected by the female (Wood and Bjorndal 2000). This was useful to define the existence of a pattern in nest site selection. In order to establish the precise preference of an interval of humidity and of temperature during nest site selection, we divided the beach into 10-m intervals parallel to the coastline. We then analyzed humidity and temperature values every 2.5 m for all the nests placed in the interval with the highest number of nests.

Each nest was protected with a 1-m square section of 10×10 cm mesh, galvanized, welded wire, to allow the passage of hatchlings. This was placed over the nest at a 10 cm depth, so that predators such as coyotes and dogs were not able to move it (Boulon 1999).

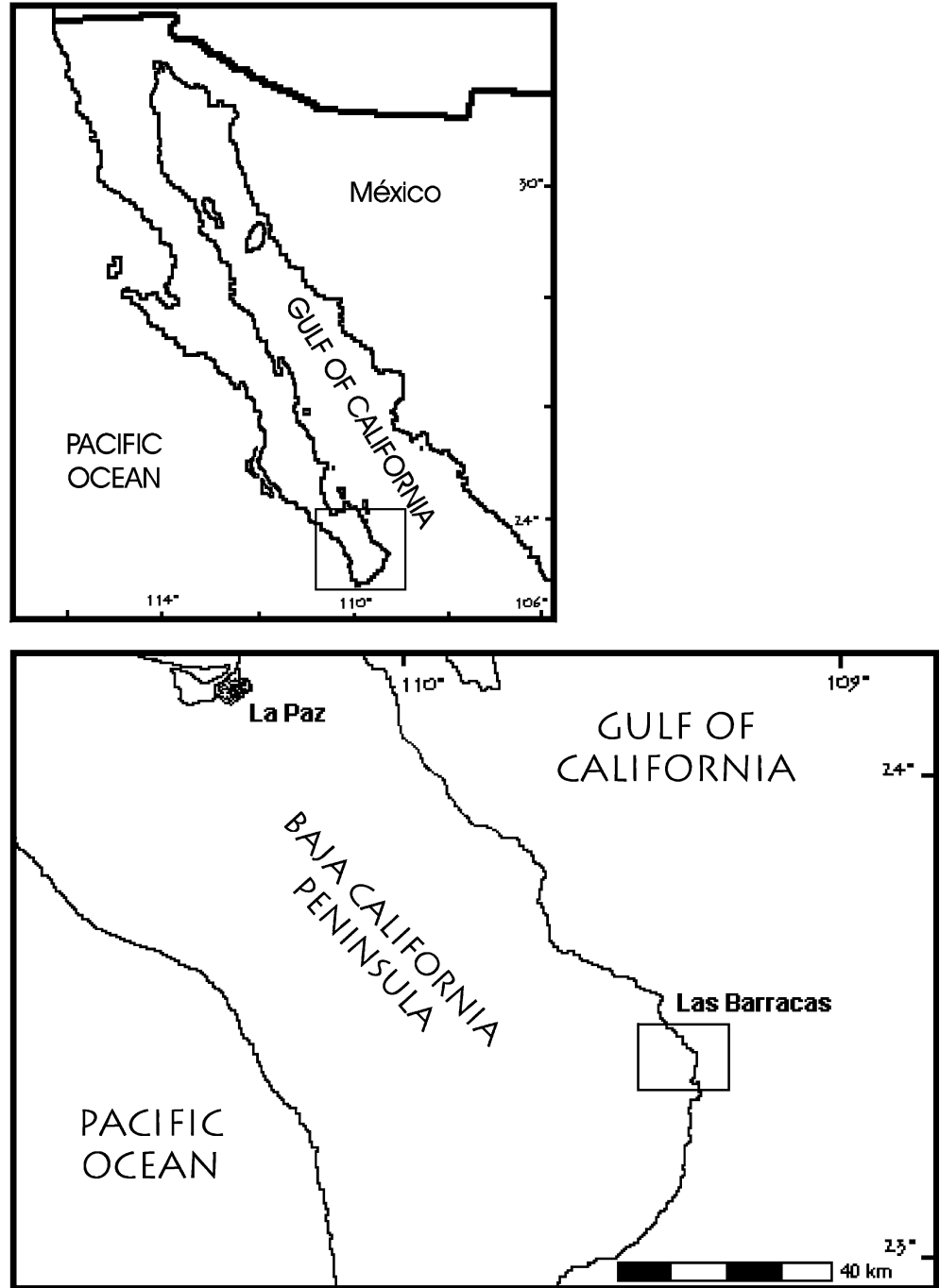
We checked the nests constantly between 45 and 70 days after oviposition. To determine nest success, we counted the number of dead hatchlings, eggs with dead embryos, unhatched eggs with no obvious embryo, and shells. Nest success was considered the percentage hatchlings that emerged from the eggs laid, or emergence success (Horrocks and Scott 1991). In order to determine the size distribution of hatchlings at birth, we measured the straight carapace length (SCL) using calipers (± 0.1 mm).

Statistical analysis

Use of statistical analysis (parametric or nonparametric) was determined applying the Kolmogorov–Smirnov test (for normality) and the Levene test (for homoscedasticity) to the group of data of each variable (humidity, temperature, distance from tide line, nest success, and mean hatchling size, the last two according to the distance, humidity, and temperature). In all cases an $\alpha=0.05$ was used. Analyses were performed with the STATISTICA 5.1 package.

If a group of data had a normal distribution and showed homoscedasticity, a one-way analysis of variance (ANOVA) was used for comparisons; otherwise we used the nonparametric equivalent, Kruskal–Wallis analysis. If the hypothesis of equality was rejected, we used an a posteriori Tukey test (parametric case) or a Kruskal–Wallis two-sample ranking test (nonparametric

Fig. 1 Study area



case) to show, in both cases, formation of homogenous groups (Zar 1999).

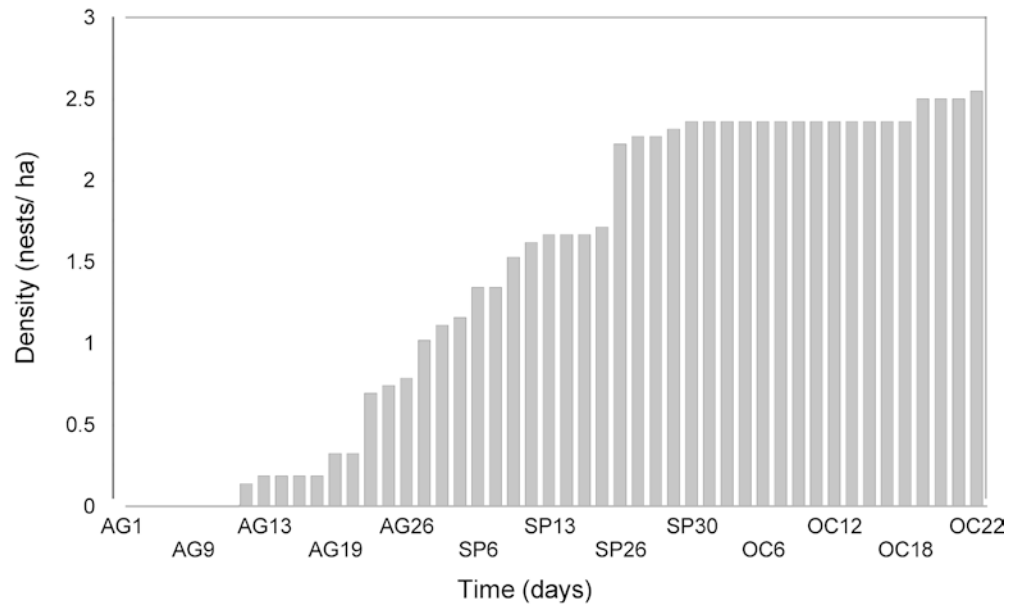
In order to determine differences in hatchling size according to the location of the nest in reference to the tide line and the influence of seasonal changes on size (Márquez 1990), we transformed sizes to percentage values considering the maximum size observed in each month to be 100%. Subsequently, we performed a chi-squared analysis of the contingency table (Zar 1999) between the frequencies of the different percentage sizes and the location of the nest in reference to the tide line.

Results

Density of nests

During this study, we counted 55 nests (Fig. 2), which corresponds to a mean density of $2.55 \text{ nests ha}^{-1}$. The highest number of new nests was registered in September (29), whereas the lowest number was recorded in October (4). Most of the nests were laid between the end of August and the end of September (Fig. 2).

Fig. 2 *Lepidochelys olivacea*. Cumulated density of olive ridley nests at Las Barracas, southern Baja California, Mexico



Nest site selection

The a priori test demonstrated that superficial humidity at the nest site and every 2.5 m towards the high tide line were not normal ($K-S=0.175$, $P<0.009$, $df=194$) or homoscedastic ($F=3.923$, $P<0.001$, $df=8$, 186). So, to observe whether there were differences between the nests and the samples taken at distance intervals of 2.5 m, we ran a nonparametric ANOVA (Kruskal–Wallis). We used this same procedure for temperature data, since they were not normal either ($K-S=0.176$, $P=0.009$, $df=191$) although they were homoscedastic ($F=1.596$, $P=0.129$, $df=8$, 183).

In the case of humidity at the nest site related to distance from the high tide mark, we found that at least one of the intervals was different ($K-W=42.817$, $P=0.001$, $df=8$); thus, we performed an a posteriori analysis to determine the group or groups that were different. There was no significant difference in humidity values from the site of the nest to 7.5 m from the tide line (Fig. 3a). The range, between 0.75% and 1.25% relative humidity, was the one preferred for oviposition (median = 1.09%). It is important to mention that the representations of humidity and temperature (Fig. 3a, b) are from the nest site to the tide line.

In the case of temperature, we found that at least one interval was different ($K-W=56.122$, $P<0.001$, $df=8$). The a posteriori test showed that the selected nest site was significantly different from the other points (Fig. 3b), indicating that turtles preferred sites where temperature at the time of oviposition was close to 32°C (Fig. 3b).

The distance between the nest site and the tide line varied from 3 to 41.5 m, with an average of 17.95 m. We found 32 nests between 10 and 20 m above the tide line (Fig. 4a). (Note: in Fig. 4a–d the abscissa represents the distance from the high tide line to the nest site).

Furthermore, we proved that between 10 and 30 m above the tide line, conditions of humidity and temperature remained relatively constant (Fig. 4d).

Clutch size

The number of eggs found in each of the 45 nests varied from 17 to 143, with a modal interval of 90–107 eggs nest⁻¹ and a mode of 102.

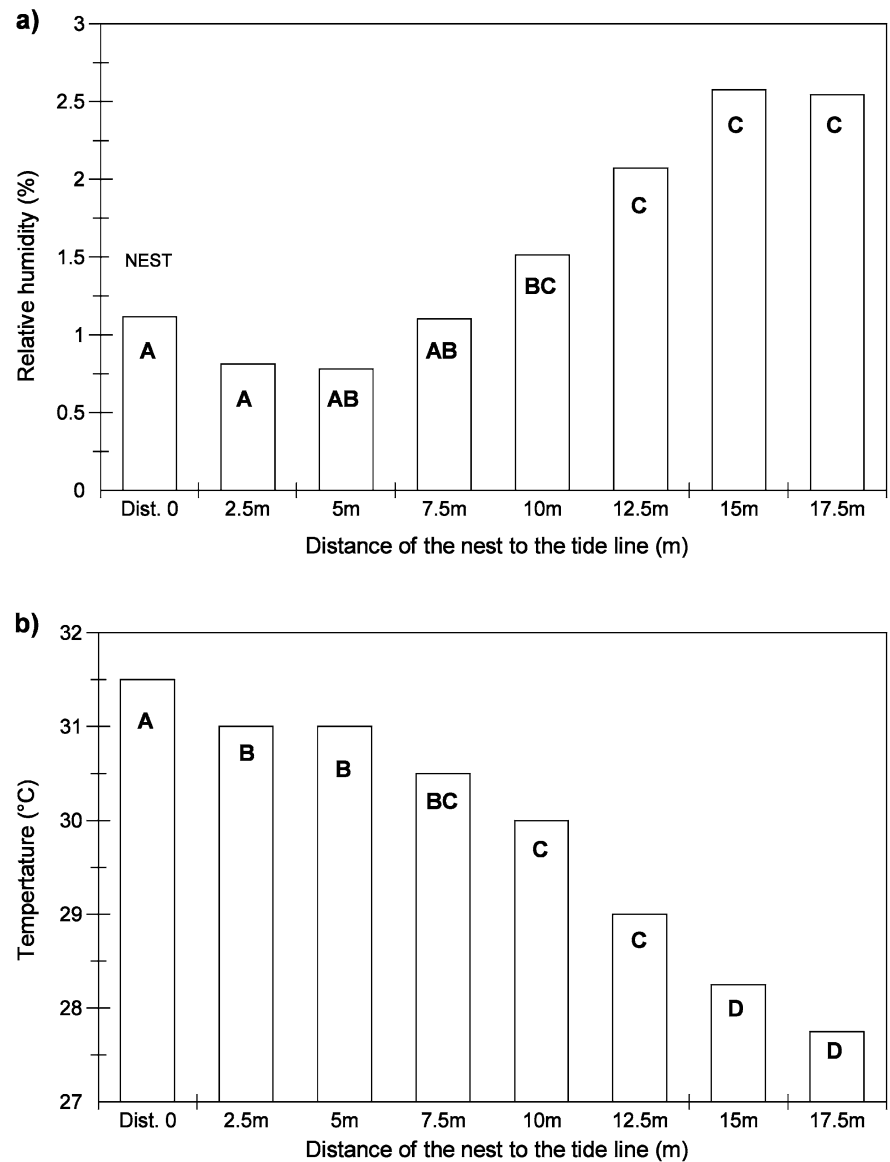
Nest success

On 9 September 2000, a storm affected ten nests that could not be located afterwards, so it was impossible to determine survival in these cases. These nests were not considered in further analysis. We counted a total of 4,031 eggs during the whole season, and we estimated an egg success of 73.73% and a mortality of 26.27% (23.76% dead hatchlings or embryos and 2.51% unhatched eggs with no obvious embryo).

Effect of humidity, temperature, and high tide line distance in nest success

Since the a priori tests demonstrated that humidity and temperature of the 18 nest sites analyzed were not normal ($K-S=0.285$, $df=17$, $P<0.01$; $K-S=0.285$, $df=17$, $P<0.01$, respectively), or homoscedastic ($F=5.52$, $df=1$, 16, $P=0.001$; $F=1.987$, $df=1$, 16, $P=0.177$, respectively), we performed a Kruskal–Wallis two-sample ranking test in order to evaluate their effect on nest success. Two different intervals for each factor were analyzed: <1% and >1% for humidity and <31°C and >31°C for temperature.

Fig. 3a, b *Lepidochelys olivacea*. **a** Superficial humidity and **b** superficial temperature at different distances from the nest of *L. olivacea*. In both cases, the same letters imply no significant differences



According to the results of the humidity and temperature analyses of the 18 nest sites considered, we determined that the temperature at the time of nesting did not affect nest success ($K-W=2.142$, $df=1$, $P=0.143$). That is, in both intervals, nest success can be considered statistically the same. However, we did observe an effect caused by humidity ($K-W=404.959$, $df=1$, $P<0.001$), obtaining higher nest success values for sites where relative humidity was $\leq 1\%$.

As for the distance between the nest and the tide line, the a priori tests showed that data were not normal ($K-S=0.244$, $df=44$, $P<0.001$). Therefore, to determine the possible effect of distance on nest success, we analyzed 45 of the nest sites using a Kruskal–Wallis ranking test. We grouped these nest sites into four intervals according to their closeness to the tide line and then observed for any differences between them regarding hatch success.

The analysis demonstrated that at least one of the intervals was different ($K-W=61.049$, $df=3$, $P<0.001$), so we ran an a posteriori analysis to identify the homogeneous groups. We observed that the highest nest success was found in the nests located between 20 and 30 m above the tide line, followed by that at the nest sites between 10 and 20 m. Nest sites found <10 m and those >30 m were grouped by the analysis; at these sites nest success was low (Fig. 4b).

Size of hatchlings

According to the a priori tests, the sizes of hatchlings by month (September, October, and November) were not normal ($K-S=0.1418$, $df=37$, $P=0.02$; $K-S=0.1017$, $df=313$, $P<0.01$; $K-S=0.0713$, $df=524$, $P<0.01$, respectively), though they were homoscedastic ($F=86.82$,

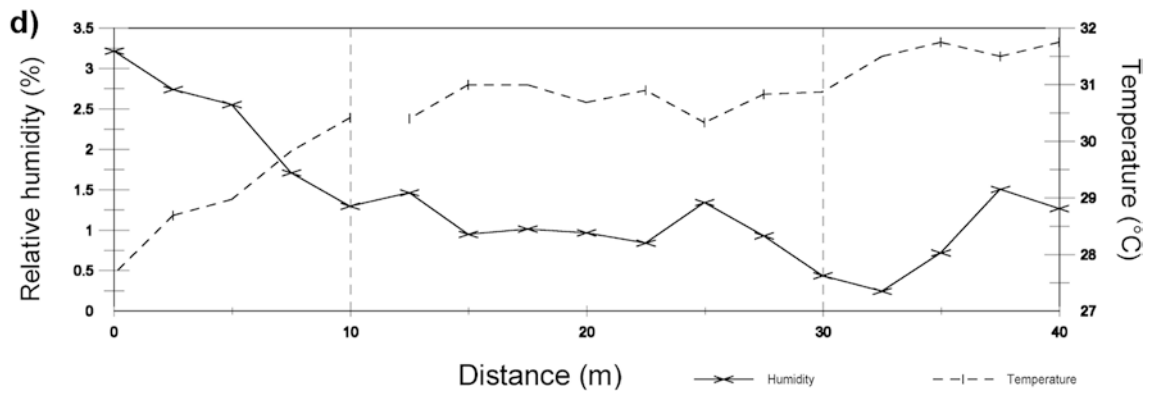
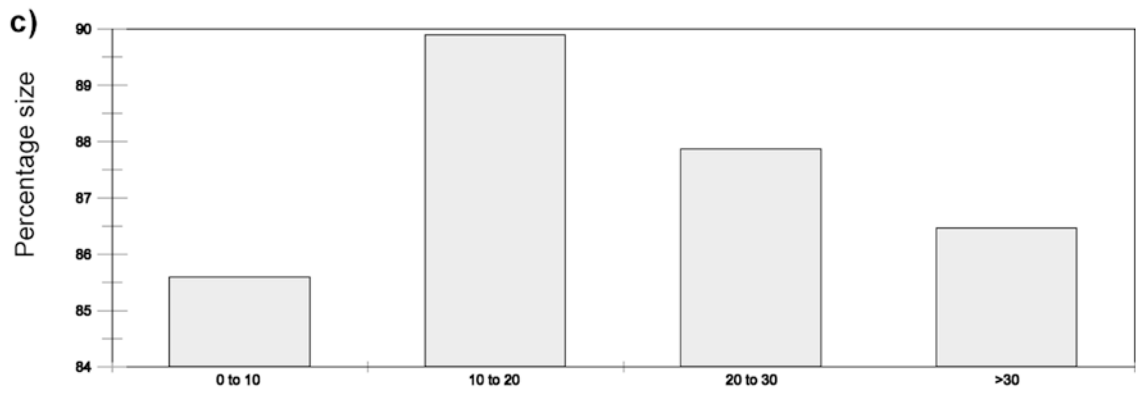
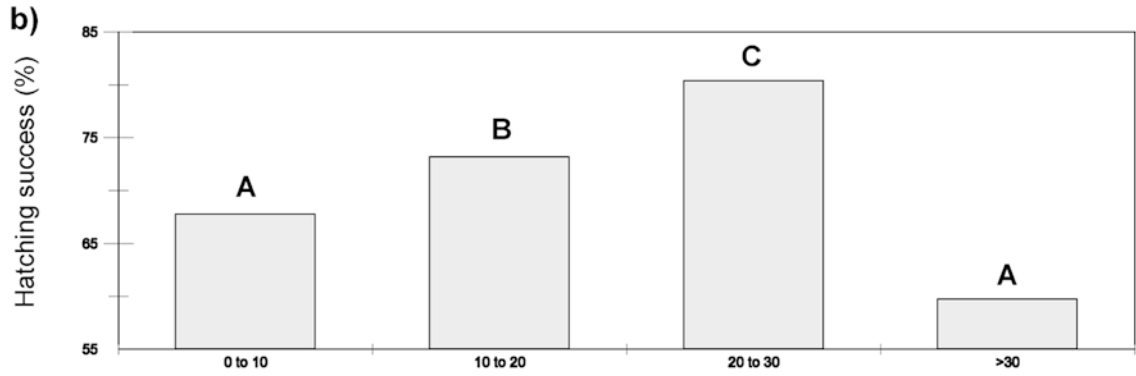
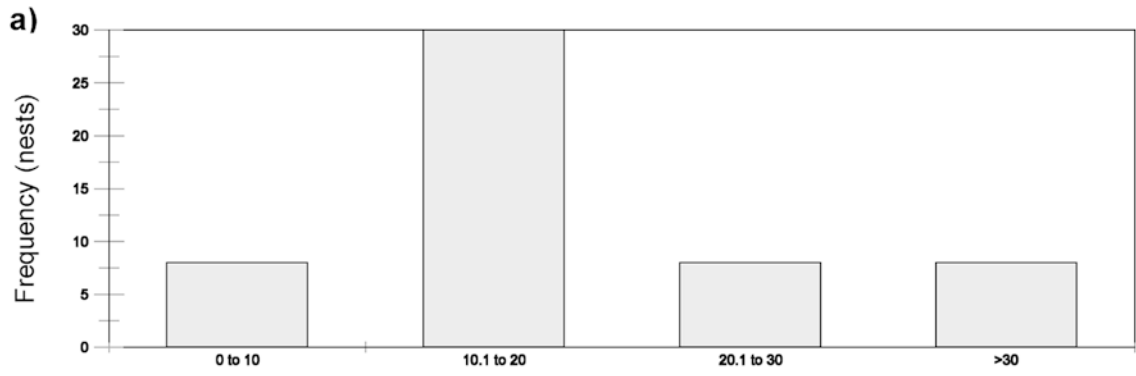




Fig. 4a–d *Lepidochelys olivacea*. **a** Frequency of the nests of olive ridley turtle based on the tide line. **b** Effect of distance between the high tide line and the nest site on the nest success of *L. olivacea*. The same letters imply no significant differences. **c** Standardized size of hatchlings (represented in percentages) of olive ridley turtle according to the nest site and the distance to the tide line in Las Barracas, southern Baja California, Mexico. **d** Relation of humidity and temperature with distance to the tide line

$P < 0.001$, $df = 2$, 871); thus, we performed a Kruskal–Wallis ranking test to determine any differences between them (Fig. 5).

We found a significant difference between months (K–W = 379.839, $P < 0.001$, $df = 2$, 874). The a posteriori test did not find homogeneous groups, which confirmed the difference mentioned above. The smallest sizes were found in November (mode = 40 mm, average = 40.5 mm; $n = 524$) and the largest in October (mode = 45 mm, average = 44.7 mm; $n = 313$); in September the mode was 44 mm, with an average of 41.8 mm ($n = 37$; Fig. 5).

We observed that the median of transformed sizes was higher at the interval between 10 and 20 m above the tide line, followed by the median at the 20–30 m interval and the smallest medians were observed at the other two intervals (< 10 m and > 30 m above the tide line) (Fig. 4c). According to this, the statistical analysis showed that the frequency of percentage sizes depended on the position of the nest ($X^2 = 317.75$, $df = 18$, $P < 0.005$).

Discussion and conclusions

Density of nests

Nesting of *Lepidochelys olivacea* at Las Barracas Beach is of the solitary type (Plotkin et al. 1997). The low number of nests is related to the combination of high temperature and low humidity. These characteristics result in the reduction of suitable areas for nesting, since the sand on most of the beach is too dry and makes construction of the egg chamber difficult (Mortimer 1990). For this reason most of the nests were located a few meters above the high tide line, where the humidity level allowed their construction.

Nest site selection

Nest success is strongly affected by site selection and the site's physical characteristics (Horrocks and Scott 1991). Generally, it has been observed that the temperature (Roosenburg 1996), beach slope (Wood and Bjorndal 2000), and humidity are important in site selection. These same factors also influence the level of activity and speed of displacement of hatchlings from the nest to the sea (Mortimer 1990; Hendrickson 1996). Specifically, we found that, in Las Barracas, humidity and temperature

played important roles in the selection of suitable sites for oviposition.

When analyzing the superficial temperature and humidity of all the nest sites, we found that reproductive females showed a nest site selectivity based on both factors, but especially on humidity, which decreased considerably at distances further away from the tide line. The preference of females for places where the temperature was close to 32°C coincides with the incubation range proposed for the species, which lies between 26°C and 33°C (Miller 1997). Before they are laid, the eggs have a temperature between 29°C and 32°C, which is the internal temperature of the female (Spotila et al. 1997). Hence, it is possible that this similarity in temperatures (nest and female temperatures) avoids metabolic alterations in the embryos due to drastic changes of temperature (Ackerman 1997).

Superficial humidity presented a wider range of values compared to temperature. This could be due to the tidal changes at or near the moment of oviposition (Turner 1993). These same changes influence humidity notably, especially within the range in which we observed nests.

We noticed a clear preference of turtles to nest at sites where the relative superficial humidity was close to 1%. These nests were located between 10 and 20 m above the tide line, where superficial temperature was coincidentally close to 32°C. Apparently, nests were placed close to the tide line to maintain constant humidity despite the risks involved. Turtles nest close to the tide line, as humidity must remain relatively constant inside the nest to allow the exchange of water, oxygen, and carbon dioxide between the embryos and the environment (Ackerman 1997). Moreover, humidity could help to prevent thermal increments caused by high temperatures in the environment and to increase the viability of developing eggs (Miller 1997).

Clutch size and nest success

The modal number of eggs per nest (102) was similar to the mean clutch size previously registered in other nesting areas of Mexico, which was 105.3 eggs (Márquez 1990).

It is difficult to compare our data on nest success with data from other areas, since in most other areas relocation and artificial incubation of nests are carried out, and only few records of nest success in situ are available. In these, success rates from 29.05% in Mismaloya, Jalisco (Trejo-Robles et al. 2000), to 80% while controlling predation (Hirth 1980) have been reported. However, nest success with ex situ techniques also varies, between 50% (Renán-Galindo 1995), 61.26% (in Playa Ceuta, Sinaloa; Amador-Medina et al. 2000), 68.35% (Villa del Mar, Jalisco; Castellanos et al. 2000), 69.83% (Lagunas de Chacahua, Oaxaca; Gonzalez-Padilla 2000) and 89.56% (La Encrucijada, Chiapas; Dominguez-Bello et al. 2000), and, in some cases,

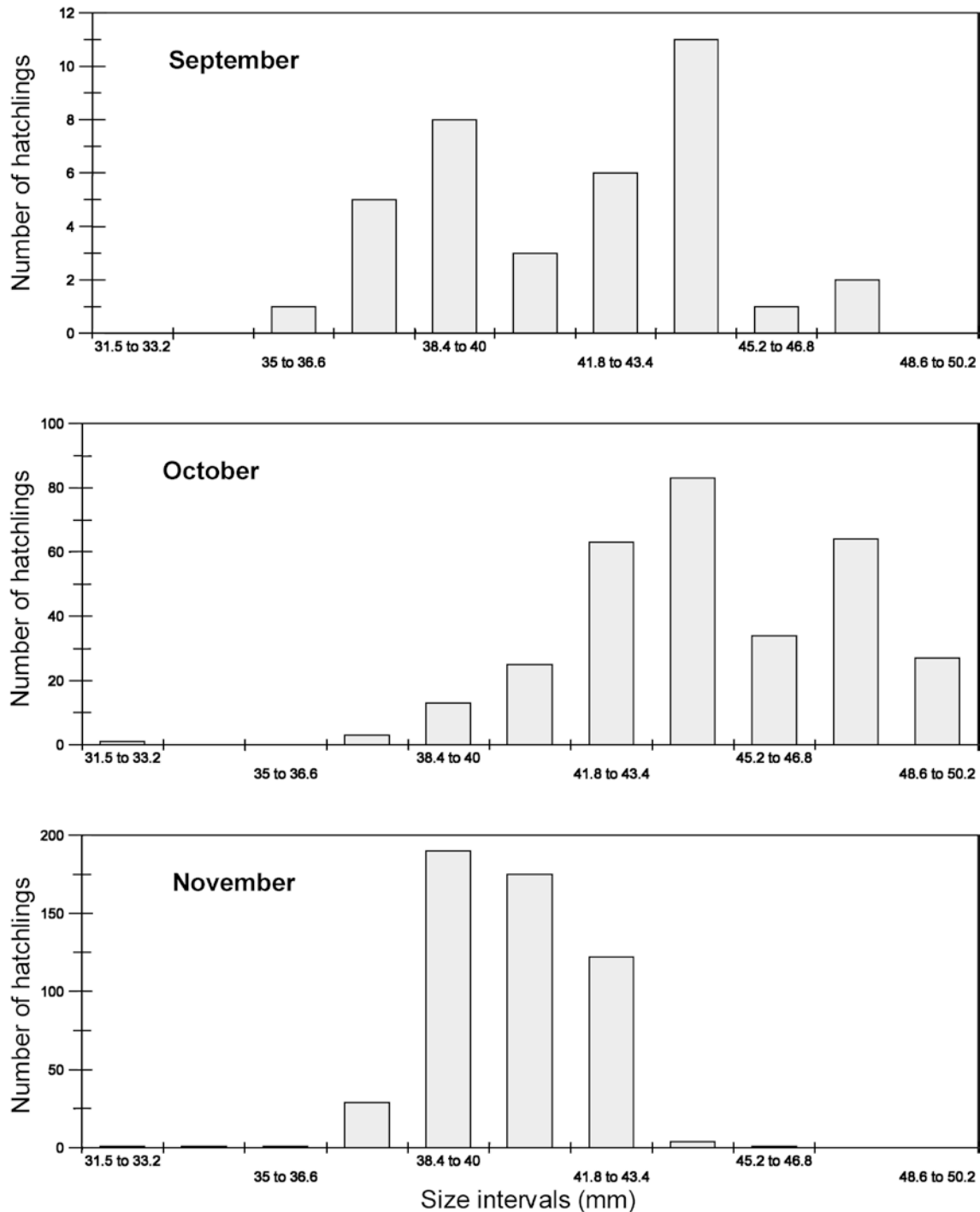


Fig. 5 *Lepidochelys olivacea*. Size of hatchlings by month of olive ridley turtle observed in Las Barracas, southern Baja California, Mexico

hatchlings are born weak and the survival rate is low (Lutcavage et al. 1997). Nest success in Las Barracas (73.73%) can be considered high, and hatchlings do not appear to have problems crawling out of the nest or getting into the water. For this reason, we suggest detailed analysis of the conditions under which relocation and artificial incubation of nests are being carried out, since apparently a greater number of nests are being

protected with ex situ methods, but nest success is low and the expenses are high.

Effect of humidity, temperature, and high tide line distance on nest success

With regards to the distance intervals analyzed, the highest nest success was found between 20 and 30 m above the tide line; this suggests that the optimum conditions of humidity and temperature are found

within this interval. The lowest nest success in the two extreme intervals is due to the fact that, at < 10 m, nests are exposed to wave action and humidity is too high to allow good embryonic development. On the other hand, at > 30 m, humidity is much lower and temperature is higher, which also negatively affects development of hatchlings (Fig. 4b).

As for superficial temperature, we did not observe a significant effect on nest success. This may have been because the values recorded here fall into a very narrow interval (Ackerman 1997). However, high temperature inside the nest did cause acceleration of embryonic development (Miller 1997), reducing the incubation period to a minimum of 45 days.

In contrast, we observed a clear effect of superficial humidity, since a higher survival rate was obtained in places where it was < 1%, values that, in general, are within the optimum range mentioned before. Presumably the low nest success in places with humidity > 1% is because these nests are closer to the water and, therefore, exposed to an "excess" of humidity (Turner 1993; Ackerman 1997), which leads to fungus development and an increase in the mortality of hatchlings (Packard and Packard 1994); furthermore these nests are exposed to wave action.

Locations of the nests in Las Barracas contrast with those observed in Sinaloa (> 50 m), probably because humidity is higher and the probability of the nests being destroyed by erosion caused by waves is low (Ríos-Olmeda, personal communication).

Size of hatchlings

The average hatchling size of *L. olivacea* in Mexico is 39 mm SCL (Márquez 1990), one of the smallest recorded. The mean size observed in other nesting areas in Mexico is 40.3 mm, in Playón de Mismaloya, Jalisco and La Escobilla, Oaxaca (Márquez et al. 1976). In contrast, the mean hatchling size in Las Barracas was 42.1 mm SCL, higher than that in other parts of the country. This difference could be derived from two non-exclusive factors: (1) the colony nesting on the peninsula may be different from that found in the rest of the Mexican Pacific or (2) the high temperature in this incubation area may give embryos the chance to channel excess energy towards their size, as occurs in *Caretta caretta* embryos (Foley 2000).

As for the sizes according to month, we observed the largest hatchlings in October and the smallest in December (Fig. 5). Apparently the humidity-temperature interaction was reflected, since, as in other nesting areas, a decrease in size was observed as the season progressed (Márquez 1990), due to fluctuations of temperature and humidity through time. The temperature was highest in September, so larger sizes were obtained; there was a slight decrease in temperature in October, but it remained within the optimum range, and presumably the humidity increased, since tides were higher

than those in September; these conditions caused an increase in size. Finally, in November, despite the optimal level of humidity, there was a strong decrease in temperature, which resulted in smaller sizes. Similarly, incubation periods were also related to temperature. Elapsed times were similar in September and October (42–45 and 44–46 days, respectively), but were extended in November (45–72 days), the month with the lowest temperature.

Since fluctuations in temperature and humidity through time evidently affect the size of hatchlings, it is possible that nest site selection can affect sizes as well. Hence, sizes determined for the three months were standardized by converting them to percentages (maximum size equal to 100%). We found that between 10 and 30 m above the tide line, the largest sizes were found (within the optimum area), but above and below these intervals sizes decreased because conditions were not optimal.

Recommendations

We recommend the in situ protection of nests, not only because high percentages of nest success are obtained (Carretero-Montes and Trejo-Robles 2000), but also because the natural sex ratio of hatchlings is maintained (Boulon 1999). The effort involved in taking care of in situ nests may be greater, because constant patrols of the beach are required; however, results may be better from a biological point of view.

If relocation of nests is necessary, a superficial humidity of < 1% and a superficial temperature of 32°C are good indicators of the minimum conditions for nest construction in Las Barracas, southern Baja California.

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